Joint Description of Charge Distributions and Correlations between Neutral and Charged Particles in the π^-p and π^-n Interactions at $P = 40$ GeV/c.

V. G. GRISHIN, G. JANCSÓ, S. P. KULESHOV, V. A. MATVEEV and A. N. SISSAKIAN
Joint Institute for Nuclear Research
Laboratory of Theoretical Physics, Laboratory of High Energy - Moscow

(ricevuto il 25 Giugno 1973)

Recent experiments on π^-p and π^-n collisions at the negative pion momentum $P = 40$ GeV/c, carried out on the two-meter propane chamber at Serpukhov, have manifested undoubtedly a linear dependence of the average number of neutral pions on the number of charged tracks (1). Experiments which have been made on ISR at CERN and also in NAL at Batavia justify this regularity by the example of pp collisions at energies ~ 1500 and ~ 200 GeV (2,3). We note here that at lower energies the effect of the correlation between neutral and charged pions appears considerably weaker.

In this paper we will present a joint quantitative description of charge distributions and correlations of neutral pions and charged tracks in π^-p and π^-n interactions at $P = 40$ GeV/c. And in this description we will employ a phenomenological model (4,5) based on those knowledges about multiparticle production at high energies which have been achieved in studies of the coherent-state model (6) and of the field theory models in the straight-line path approximation (7).

Let us point out that for the first time a theoretical hint about the linear dependence of the average number of neutral pions on the number of charged particles, within the framework of the model under consideration, has been given in ref. (5). In a number of

(1) DUBNA-BUDAPEST-BUCHAREST-VARSAVA-KRAKOW-SERPUKHOV-SOFIA-TBILISI-ULAN BATOR-HANOI COLLABORATION: JINR P1-6491, Dubna (1972); *Yad. Fiz.*, **16**, 989 (1972); JINR P1-6928, Dubna (1973).
(2) G. FLÜGGE, CH. GOTTFRIED, G. NEUHIFER, F. NIEBERGALL, M. REGLER, W. SCHMIDT-PARZEFALL, K. R. SCHUBERT, P. E. SCHUMACHER and K. WINTER: CERN preprint (1972).
(3) G. CHARLTON, Y. CHO, M. DERRICK, R. ENGELMANN, T. FIELDS, L. HYMAN, K. JAEGER, U. MEHTANI, B. MUSGRAVE, Y. OVEN, D. RHINES, P. SCHREINER, H. YUTA, L. VOYVODIC, R. WALKER, J. WHITMORE, H. B. GRAWLEY, Z. MING MA and R. G. GLASSER: NAL preprint (Argonne, 1972).
(4) V. G. GRISHIN, G. JANCSÓ, S. P. KULESHOV, V. A. MATVEEV and A. N. SISSAKIAN: JINR, E2-6596, Dubna (1972); *Yad. Fiz.*, **17**, 1281 (1973); JINR, P2-6950, Dubna (1973).
(5) S. P. KULESHOV, V. A. MATVEEV and A. N. SISSAKIAN: IRB-TP-72-3 preprint, Zagreb (1972); *Fizika*, **5**, 67 (1973).
(6) V. A. MATVEEV and A. N. TAVKHELIDZE: JINR, E2-5141, Dubna (1970); S. P. KULESHOV, V. A. MATVEEV and A. N. SISSAKIAN: JINR, E2-5898, Dubna (1971).
(7) B. M. BARBASHOV, S. P. KULESHOV, V. A. MATVEEV, V. N. PERVUSHIN, A. N. SISSAKIAN and A. N. TAVKHELIDZE: *Phys. Lett.*, **33** B, 484 (1970).

recent works (see, *e.g.*, ref. [8]) the linear correlation is discussed on the basis of various assumptions about the isotopic properties of clusters and their decay laws. As we have no possibilities to consider in detail all the numerous approaches to the given problem, we simply refer the reader to the reviews [9].

The main point of the discussed model is the assumption that there exist two mechanisms for secondary-particle production. These are as follows:

i) there exist the leading particles which can dissociate with local conservation of isospin;

ii) in the interaction process the hadron associations are also produced in a statistically independent way, then they decay into pions.

It is quite natural to suppose that the mean numbers of these hadron associations do not depend on the type of colliding particles at high energies.

A comparison of the model with experiment indicates that, to describe charge distributions and correlations between neutral and charged particles in π^-p and π^-n interactions at $P = 40$ GeV/c, it is sufficient to consider only the simplest channels of dissociation of the colliding particles and the hadron associations with isospin $I = 0$. Thus, we consider the dissociation of the leading nucleon $\mathcal{N}$ in the following scheme (*):

i) $\mathcal{N} \to \mathcal{N}$ with probability α_1,

ii) $\mathcal{N} \to \mathcal{N}\pi^0$ with probability α_2,

iii) $\mathcal{N} \to \mathcal{N}'\pi^\pm$ with probability α_3.

Here $\sum_{i=1}^{3} \alpha_i = 1$, and, in addition, $\alpha_3 = 2\alpha_2$ by the assumption of local isospin conservation.

As another source for secondary-particle production let us introduce the σ and ω associations which are produced by the Poisson law, with isospin $I = 0$ and G-parity $G = \pm 1$. We confine ourselves to the main schemes for decays of the σ and ω associations:

i) $\sigma \to \pi^+\pi^-$, $\pi^0\pi^0$,

ii) $\omega \to \pi^+\pi^-\pi^0$.

Keeping in mind the model assumptions, one can easily see that the production probability for a number of pairs $n_\pm$, n_0 and of triplets of pions n_3, at the given channel i of the dissociation of the leading nucleon, is defined as follows:

$$W^i_{n_\pm, n_0, n_3} = \alpha_i P_{n_\pm}(a_\pm) P_{n_0}(a_0) P_{n_3}(b) , \tag{1}$$

where $P_n(\bar{n})$ is the Poisson factor, and $a_\pm$, a_0, b are the average numbers of pion pairs $\pi^+\pi^-$, $\pi^0\pi^0$ and of pion triplets $\pi^+\pi^-\pi^0$, respectively. From the condition that the pairs $\pi^+\pi^-$ and $\pi^0\pi^0$ are produced with isospin $I = 0$, $a_\pm = 2a_0 \equiv a$ follows.

---

(8) E. L. BERGER, D. HORN and G. H. THOMAS: NAL preprint, Argonne, Ill. (1972); D. HORN and A. SCHWIMMER: CALT preprint, Cal. (1972).

(9) A. WROBLEWSKI: rapporteur talk at the *Kiev Conference* (1970); M. JACOB: rapporteur talk at the *Batavia Conference* (1972); R. MURADYAN: *Automodelity in inclusive reactions* (in Russian); JINR, P2-6762, Dubna (1972).

(*) For the sake of simplicity we do not consider strange-particle production.

It is evident that the numbers of charged particles n_c and neutral pions n_{π^0} can be represented in the following manner:

$$n_c^i = 2n_\pm + 2n_3 + l_c^i \,, \tag{2}$$

$$n_{\pi^0}^i = 2n_0 + n_3 + l_{\pi^0}^i \,, \tag{3}$$

where l_c^i, $l_{\pi^0}^i$ are the numbers of charged particles and π_0-mesons among the products of the dissociation of the leading particles in the i-th dissociation channel (see Table I).

TABLE I.

	$i=1$		$i=2$		$i=3$	
	π^-p	π^-n	π^-p	π^-n	π^-p	π^-n
l_c	2	1	2	1	2	3
l_{π^0}	0	0	1	1	0	0

From the formula (1) for the distributions of the number of charged particles it follows:

for π^-p interactions

$$W_{n_c}(\pi^-\text{p}) = P_{(n_c-2)/2}(a') \,, \tag{4}$$

for π^-n interactions

$$W_{n_c}(\pi^-\text{n}) = (1-2\alpha_2)P_{(n_c-1)/2}(a') + 2\alpha_2 P_{(n_c-3)/2}(a') \,, \tag{5}$$

where $a' \equiv a + b$ has the meaning of the mean number of pairs $\pi^+\pi^-$ including a contribution from similar combinations among the pion triplets $\pi^+\pi^-\pi^0$.

A comparison of the formulae (4) and (5) with the experimental data at $P = 40$ GeV/c reveals good agreement (see Fig. 1 and Table II). We have also found the value of the

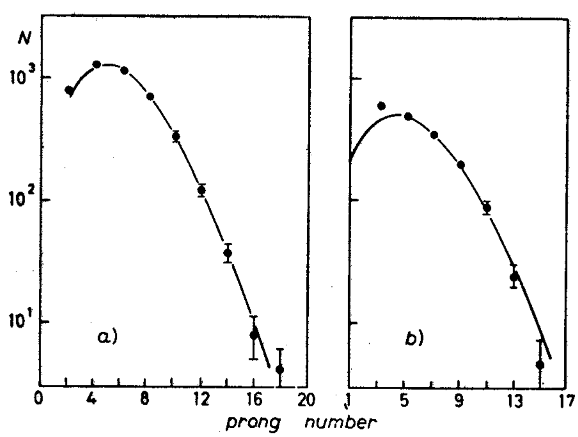

Fig. 1. – a) $\chi^2 = 8$, π^-p at $P = 40$ GeV/c; b) $\chi^2 = 8.5$, π^-n at $P = 40$ GeV/c.

TABLE II.

Type of inter-action	Number of events	$\bar{n}$	$\sqrt{D}$	χ^2 fit by the Wang I model	χ^2 fit by the suggested model	Degrees of freedom
π^-p	4400	5.62 ± 0.4	2.75	8	8	8
π^-n	1860	5.32 ± 0.7	2.82	13	8.5	7

average number of $\pi^+\pi^-$ combinations ($a' = 1.81 \pm 0.02$) and the nucleon charge exchange coefficient ($2\alpha_2 = 0.36 \pm 0.04$). Unlike the Wong-I model ([10]), if one uses a distribution of the type of a superposition of Poisson factors with the same number of parameters, a good joint description for π^-p and π^-n collisions with the same average value of $\pi^+\pi^-$ combinations a' may be given (*).

As a second step in the use of the distribution (1), it is not difficult to obtain a formula describing the average number of neutral pions at a fixed value of the charged-track number n_c. From (3) it follows that

$$\langle n_{\pi^0}\rangle_{n_c} = \frac{2\langle n_0\rangle_{n_c} + \langle n_3\rangle_{n_c} + \langle l_{\pi^0}\rangle_{n_c}}{W_{n_c}}. \tag{6}$$

After some calculations we find from (6) the following expression for the π^-p interaction:

$$\langle n_{\pi^0}\rangle_{n_c} = k_1 + k_2(n_c - \bar{n}_c), \tag{7}$$

where $k_1 = a' + \alpha_2$, $k_2 = b/2a'$, and $\bar{n}_c = 2a' + 2$ is the average number of charged particles in π^-p interactions.

For the case of the π^-n interaction such a dependence is somewhat complicated ([4]); however, under the condition that the parameter α_2 is small ($\alpha_2 = 0.18$), from (1) and (6) the linear dependence of the average number of neutral pions $\langle n_{\pi^0}\rangle_{n_c}$ on the number of charged tracks n_c follows, as well. In this case the correlation is defined by (7) with the average number of charged particles in π^-n interactions $\bar{n}_c = 2a + 2\alpha_2 + 1$.

To compare formula (7) with experiment an additional parameter Δ has been inserted into (7), which means some correction due to a possible charge exchange process in π^-p interactions ($\pi^-p \to \pi^0 n + \ldots$), and also to other possible dissociation channels of the leading particles ([4]): $k_1 \to k_1 + \Delta_{\pi^-\mathcal{N}}$.

At the present time data with great statistics (6000 γ-quanta) on the dependence of the average number of π^0-mesons on the number of charged particles have been obtained for π^-p and π^-n interactions at $P = 40$ GeV/c ([1]). The results of a comparison of the proposed model with these data are shown in Fig. 2. The parameters are as follows: $b = 0.56 \pm 0.06$, $\Delta_{\pi^-p} = 0.42 \pm 0.05$; and the parameters a' and α_2 were taken from the charge distribution fit. Good agreement with experiment ($\chi^2 \approx 0.5$ with one degree of freedom) confirms the prediction of the model about the linear form

(*) We note that most of the other models (Wong-II, Poisson, etc.) do not provide a sufficient description of the experimental data at $P = 40$ GeV/c.

([10]) C. P. WANG: *Nuovo Cimento*, **64 A**, 546 (1969); *Phys. Rev.*, **180**, 1463 (1969); *Phys. Lett.*, **30 B**, 115 (1969).

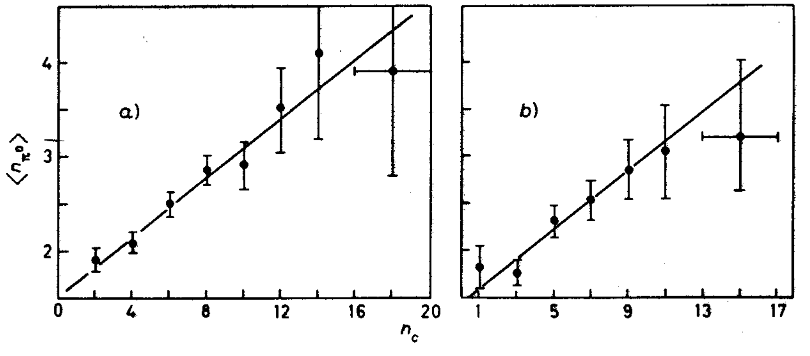

Fig. 2. – a) π^-p at $P_c = 40$ GeV/c; $\chi_5^2 = 2$, $b = 0.56 \pm 0.06$, $\Delta = 0.42 \pm 0.05$. b) π^-n at $P_c = 40$ GeV/c; $\chi_5^2 = 3$, $b = 0.56 \pm 0.06$, $\Delta = 0.04 \pm 0.08$.

of the correlation:

$$\langle n_{\pi^0} \rangle_{n_c} = A + Bn_c\,. \tag{8}$$

It is worth noting that the slope B coincides, within errors, for π^-p and π^-n interactions ($B_{\pi^-p} = 0.16 \pm 0.02$, $B_{\pi^-n} = 0.15 \pm 0.02$); this is one of the conclusions of the model. Indeed, the slope is related to the ratio of the average number of hadron dissociations

$$B = \frac{1}{2}\frac{\bar{N}(\omega \to \pi^+\pi^-\pi^0)}{\bar{N}(\sigma \to \pi^+\pi^-) + \bar{N}(\omega \to \pi^+\pi^-\pi^0)} \tag{9}$$

which were assumed to be independent of the type of colliding particles.

As is known, the experimental data obtained on ISR in pp collisions also demonstrate a dependence of the type of (8), but the slope $B \approx \frac{1}{2}$ and A is small. Within the framework of the suggested simple model the absence of correlations between $\langle n_{\pi^0} \rangle_{n_c}$ and n_c at $E \leqslant 20$ GeV and the limiting dependence $\langle n_{\pi^0} \rangle_{n_c} = \frac{1}{2} n_c$ at $E \approx 2000$ GeV can be naturally explained, if $\bar{N}(\omega) \ll \bar{N}(\sigma)$ at low energies, *i.e.* $B \approx 0$, is assumed; and with increasing energy a fraction of the σ-associations disappears and we have $\bar{N}(\omega) \gg \bar{N}(\sigma)$, *i.e.* $B = \frac{1}{2}$.

* * *

We are very pleased to thank A. M. BALDIN, R. M. MURADYAN, L. A. SLEPCHENKO, M. A. SMONDYREV, A. N. TAVKHELIDZE for useful discussions.